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THE EFFECT OF STEEP SLOPES ON THE APPLICATION OF THE USLE, RUSLE, AND MUSLE METHODS

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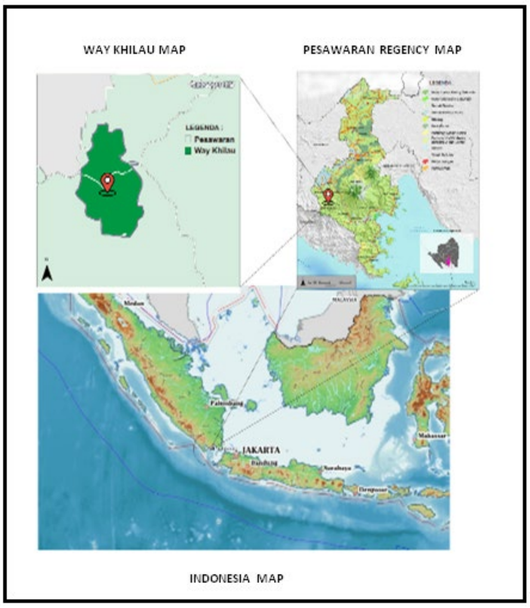
Graphical abstract



Abstract

Soil erosion and ecological environmental damage cause environmental and resource problems in the Way Khilau Sub-Sub-Watershed. The purpose of the study was to compare the predictions of the soil erosion rates of the universal soil loss equation (USLE), its revised model (RUSLE), and its modified version (MUSLE). This study comprises several stages; literature review, data collection, and erosion calculations. The erosion calculations were based on 3 methods; THE USLE, RUSLE and MUSLE methods, which were then analyzed for the results of the comparison. The largest erosion values of all the methods on steep slope land (25-45%) were 526.5485 tons/Ha/th with the USLE Method, 585.3 tons/Ha/th with the RUSLE Method, and 13202.38 tons/Ha/th with the MUSLE Method. The lowest erosion values of all methods on sloping slope land (0-8%) were 0.879 tons/Ha/th with the USLE Method, 0.94 tons/Ha/th with the RUSLE Method, and 22.04 tons/Ha/th with the MUSLE Method. The results of the calculations of the average erosion per year in the Way Khilau Sub-Sub-Watershed with the USLE and RUSLE methods fall into the medium category (S), while with the MUSLE Method, it falls into the very heavy category (SB). In conclusion, the USLE and RUSLE soil erosion models had relatively similar results, yet the MUSLE model showed a higher spatial difference in erosion potential than the other models.

Keywords: erosion, Way Khilau Sub-Sub-Watershed, USLE, MUSLE, RUSLE.

1.0 INTRODUCTION

Soil erosion and ecological environmental damage due to soil erosion have become the center of resource and environmental problems nowadays. Erosion by water is one of the most serious soil degradation current problems [1].

Estimation of soil erosion using empirical models has been an interesting research topic for decades. There are more erosion models, equations, and models empirically generated by research for soil erosion mechanisms. Each method is adapted to the condition of the field and its problems. So, their uses vary. The parameters encompass such factors as country differences, watershed areas, regional topological conditions, and other condition differences.

Here is a brief introduction to the models used in this study [2]:

1. USLE (Universal Soil Loss Equation) is an early empirical model based on relevant influential factors and is widely used in many countries. However, since it originated from the United States, the calculation of any factor should be revised when it is applied in a different environmental region.
2. RUSLE (Revised Universal Soil Loss Equation) is a new version of USLE that has been improved and developed. RUSLE retains the basic form of the USLE equation, but improves the calculation of each factor. The sensitivity of the soil to the rill is considered when the inclination factor of the slope increases in length, and is visible on a slope above 20 % [3].
3. MUSLE (Modified Universal Soil Loss Equation) is a development of the USLE equation whose basis is rainfall-runoff. This model replaces the precipitation factor (R) with a momentary peak flow and total runoff factor for the soil erosion prediction.

The USLE equation and its revised version (RUSLE) are the most frequently used soil erosion prediction models. The main problem emerging in their application is that the support of an accurate topographic representation must be there [4, 5].

The USLE model uses the one-dimensional topographic factor. If applied to a three-dimensional space, the prediction becomes more difficult than the theoretical assumptions such as runoff formation, deposition, and sediment transport. Sediment deposition and neglect of transportation result in the inability of the model to distinguish an area of clean erosion from a clean settling area. For large tracts of land, the application is inviable for the division of terrain into fields and hillsides. USLE is effectively used for small areas such as grid cells. The advantages of the USLE model provide a high spatial distribution of the erosion prediction compared to the other models as the rain factor in this model is more effective [2].

The RUSLE model still retains the basic structure of the USLE equation. RUSLE is an erosion model designed to predict the magnitude of annual erosion (A) by the surface flow of a field slope with certain plants and management systems [5]. RUSLE has also been used to predict the magnitude of erosion from rangelands and non-agricultural lands such as lands for buildings.

The USLE and RUSLE models can only estimate the average annual soil erosion in a long term and cannot calculate sediment deposition. With MUSLE, sediment deposition can be estimated since the model replaces the rainfall energy factor (rainfall energy) with the surface flow factor (runoff energy). The prediction of the sediment yield improves because the surface flow is the function of the Antecedent Moisture Condition (AMC) and rain energy [7]. Including the runoff factors as independent factors, the MUSLE erosion model improves the accuracy of the soil erosion prediction so much that it is more accurate than USLE and RUSLE.

Slope is one of the factors that have major (dominant) effects on erosion [8]. Erosion gets bigger if the slope gets steeper [9]. The inclination of the slope affects the speed of the surface runoff. The greater the inclination, the slimmer the chance water gets into the soil (infiltration) so that the volume of the surface runoff is greater and it leads to erosion.

The results of the research of the Capacity Development for Implementing Rio Conventions through Enhancing Incentive Mechanisms for Sustainable Watersheds/Land Management (CCCD) team in 2018 indicate that the inclination of the slope in the Khilau Sub-Sub-Watershed, Bulok Sub-Watershed, Sekampung Watershed, is a dominance of 8-15% (rather steep) This area with a rather steep to steep slope is in the upper reaches of the Way Khilau Sub-Watershed. land use change affects erosion rates [10, 11]. This is a protected forest area that has turned into community cultivation plantations such as cocoa, vegetables, rice, bananas, and coffee. The planting business implementation does not take into account the geographical marble conditions of the land. So, there is an increase in the potential for erosion and flooding. In addition, the change of protected forests into cultivated plantations also affects the existing ecosystems and habitats of flora and fauna [13]. For these reasons, there is a need for attention to the condition of the Khilau Sub-Sub-Watershed.

The purpose of the study was to compare the predictions of the soil erosion rates of the universal soil loss equation (USLE), its revised model (RUSLE), and its modified version (MUSLE) in the Khilau Sub-Sub-Sub-Watershed, their relationships with topographic factors and influence on steep slopes, and to evaluate the validity of other studies related to the nature and the approaches used in such methods.

2.0 METHODOLOGY

2.1 Research Location

The research was conducted in the Khilau Sub-Sub-Watershed, which is the headwaters of the Way Bulok watershed, the Way Sekampung Watershed of Pesawaran Regency. The main river in the Khilau Sub-sub-watershed is the Right Cong with a river length of 5 kilometers from the upper reaches of the watershed. The height difference between the highest point and the lowest point of the land is 700 meters, so that the gradient of the Khilau sub-sub- watershed is 15% [13] (Figure 1)

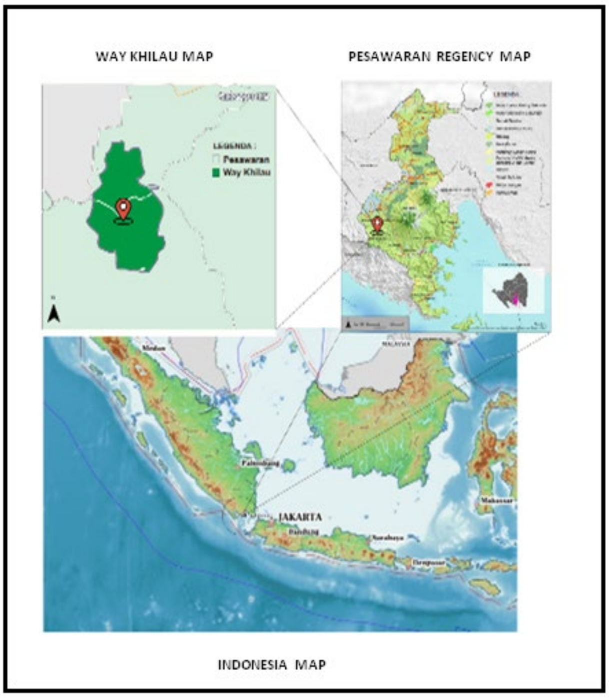


Figure 1. Map of Khilau Sub-Sub-Watershed Research Location (Source: Map of Administration of Pesawaran Regency, 2020)

2.2 Material

The data in this study, which was obtained through secondary sources and indirectly in the field, records or archives having been collected by agencies related to the issues this study concerns, i.e. the results of the research entitled The Capacity Development for Implementing Rio Conventions through Enhancing Incentive Mechanisms for Sustainable Watershed/Land Management Team (CCCD), conducted in the same location in 2018, the nearest Rain Station, and from a Thesis of Selin Handayani (2020), includes:

a) The location and area of the research obtained from the Map.
b) The data of the soil structure, soil permeability, organic matter composition, sand composition, dust composition and very fine sand.
c) The length and inclination of the erosion slope.
d) The land cover and conservation measures.
e) The data of the rainfalls from 2011 to 2020 from the nearest station.

2.3 Data Processing and Analysis

This study is composed of several sections, i.e. literature review, data collection, and erosion calculations. The erosion was calculated with 3 methods; THE USLE, RUSLE, and MUSLE methods. The calculation results were then analyzed to find out how they compared.

2.3.1 USLE (Universal Soil Loss Equation) Method

According to Wischmeier and Smith (1978)[14], the USLE model is intended to predict average long-term soil erosion from planting and processing systems with the following empirical equation:

$$A = R \times K \times LS \times C \times P \quad (1)$$

Where, A = Average Soil Erosion Magnitude (ton/ha/th), R = Rain Erosive Factor and Surface Flow, K = Soil Erodibility Factor, L = Slope Length Factor, S = Slope Steepness Factor, C = Plant Management Factor (Vegetation)/Land Cover, P = Management and Conservation Factor.

The magnitude of erosion with the USLE method is based on the following factors:

a) Rain Erosive Factor (R) with Bols' equation:

$$EI30 = 6{,}119\ (CH)^{1{,}21} (HH)^{-0{,}47}\ (H24)^{0{,}53} \quad (2)$$

Where, CH = Monthly Average Rainfall (cm), HH = Number of Monthly Average Rainy Days, H24 = Maximum Rainfall for 24 Hours in the Corresponding Month.

b) Soil Erodibility Factor (K).
The calculation of the K value using the equation of Wischmeier and Smith is as follows:

$$100\ K = 1.292\ [2.1\ M^{1.14}\ (10\text{-}4)\ (12\text{-}a) + 3.25\ (b\text{-}2) + 2.5\ (c\text{-}3)] \quad (3)$$

Where, K = Soil Erodibility, M = Soil Texture Value, a = Organic Matter Percentage, b = Soil Structure Class, c = Soil Permeability Class.

c) Factors of Length (L) and Slope (S)

$$LS : x^{0.5}\ (0.0138+0.00965\ s+0.0138\ s^2) \quad (4)$$

Where, x = Slope Length (m), s = Slope Inclination (%).

2.3.2 RUSLE (Revised Universal Soil Lost Equation) Method)

The RUSLE method is a prediction of the magnitude of annual erosion affected by a sloping landscape with specific planting and management systems [15]. The method is applied to determine the magnitude of the erosion hazard level (A) (tons/ha/yr) based on the flow direction according to the general equation of RUSLE soil loss, which is:

$$EA = Ri \times K \times LS \times C \times P \quad (5)$$

Where, EA = Average of Amount of Annual Soil Loss (t/ha/th or t/acre/th), Ri = Soil Erosive Factor/Erosion Power Index. The amount of the erosion occurring in the Khilau sub-sub watershed with the RUSLE method was found out by calculating the magnitude of the factors causing its erosion. The RUSLE method applies the following variables:

a) Factors of Rain Corrosiveness (Ri) with the equation:

$$Ri = \frac{\sum_{j-1} EI30}{N}$$

and: $(0.29\ (1\text{-}0.72^{(-0.082.\ I)}))$ MJ- ha^{-1}- mm^{-1} (6)

$$E = \sum_{k=1}^{M} e_k\, \Delta V_k \quad (7)$$

Where, V = Amount of Rainfall Occurring at the Time of Rain (mm), I30 = Rainfall Intensity of 30 Minutes (mm/h), j = Amount of Rain in N Periods.

2.3.3 MUSLE (Modified Universal Soil Lost Equation) Method

The MUSLE method measures the magnitude of the erosion of the Khilau Sub-Sub-Watershed with the following factors:

a) V_Q (Total Runoff Volume/Runoff) (m^3)
According to Bambang Triatmodjo (2009) [5, 16], the value of V_Q is obtained through the formula:

$$V_Q = D \times A \times C \times D \quad (8)$$

Where, V_Q = Volume of Surface Flow (m^3), D = Depth of Rain or Maximum Rain Height (m), A = Area (m^2), C = Factor of Flow Coefficient/Runoff, P = Factor of Tillage (without conservation)

b) Qp (Peak Flow) (m^3/s).
The value of the peak flow is calculated with the following rational method:

$$Qp = 0{,}278 \times C \times I \times A \quad (9)$$

Where, Qp = Peak Flow (m^3/s), C = Flow Coefficient/Runoff (Rational Method), I = Rain Intensity (mm/h), A = Area (km^2).

c) Rain Erosive Factors

$$R = 11.8\ (V_Q \times Qp)^{0.56} \quad (10)$$

Where, V_Q = Total Runoff Volume/Runoff, Qp = Maximum Discharge [17].

d) MUSLE Erosion Model with MUSLE Sedimentation Results (Tons) (A_{MUSLE}) on Empirical Equations.

$$A_{MUSLE} = 11.8\ (V_Q \times Qp)^{0.56} \times K \times LS \times C \times P \quad (11)$$

$$\text{If } R = 11.8\ (V_Q \times Qp)^{0.56} \quad (12)$$

Then, the MUSLE formula is obtained through the equation:

$$A_{MUSLE} = R \times K \times LS \times C \times P \quad (13)$$

3.0 RESULTS AND DISCUSSION

3.1 Results

3.1.1 Rainfall data

We present 10 years of rainfall data, Monthly Average Rainfall Data. See Table 1.

Table 1. Monthly Average Rainfall Data

No	Year	Month (mm)												Total	Rainfall
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		(cm)
1	2011	278.4	136.0	137.3	147.3	110.2	36.0	38.5	102.9	73.9	126.0	123.2	159.5	1469.3	146.9
2	2012	220.3	200.5	97.5	132.0	52.2	29.8	12.7	0.5	20.2	81.7	91.7	281.2	1220.2	122.0
3	2013	289.3	330.2	100.7	157.3	112.8	35.3	191.7	89.2	79.2	136.0	197.3	371.3	2090.3	209.0
4	2014	317.0	170.7	115.0	72.0	115.3	75.7	25.0	86.7	1.0	43.3	66.0	288.7	1376.3	137.6
5	2015	401.0	233.7	176.3	171.3	64.3	42.3	16.0	0.3	12.3	0.0	105.3	195.7	1418.7	141.9
6	2016	223.0	296.0	252.3	237.7	203.0	79.0	113.3	26.0	124.3	91.7	270.0	128.0	2044.3	204.4
7	2017	148.0	281.3	157.0	175.7	135.3	53.7	99.3	72.3	105.3	192.7	153.5	252.7	1826.8	182.7
8	2018	165.0	207.3	319.7	217.7	105.3	94.0	8.7	8.3	50.0	18.0	97.0	128.7	1419.7	142.0
9	2019	200.9	295.3	246.8	185.3	45.0	58.0	68.7	12.0	6.0	9.7	19.7	208.8	1356.3	135.6
10	2020	324.3	138.0	146.8	87.0	43.1	150.0	107.1	6.7	6.7	80.9	45.8	198.8	1335.3	133.5
Average		256.7	228.9	174.9	158.3	98.7	65.4	68.1	40.5	47.9	78.0	117.0	221.3		155.6

3.1.2 Calculation Results

a) USLE Method

- Rain Erosive Factors (R)

Rainfall data used in the last 10 years (2011-2020) was obtained from the Sukajaya rainfall planter (closest to Bayas Jaya Village). The obtained monthly corrosiveness is 1308.30 tons/ha/cm, with the highest value of 210.05 tons/ha/cm of rain (March) and the lowest value of 34.13 tons/ha/cm of rain (June).

- Soil Erodibility Factor (K).

Soil erodibility (K) is an event of soil particle resistance during exfoliation and its transport due to the kinetic energy of rainwater [18]. The constituent particles of the soil are dust, sand, and clay, with their characteristic permeability, organic matter, and soil structure.

Based on the map of the soil types in the Khilau Sub-Sub-Watershed, the majority of the types are Dystropept (Figure 2). The organic matter of the soil samples tested in the laboratory ranges from 1.78% to 5.12%.

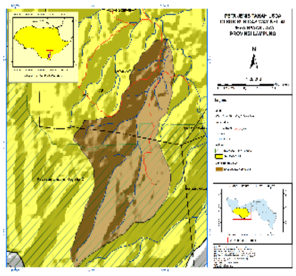


Figure 2. Map of Soil Types

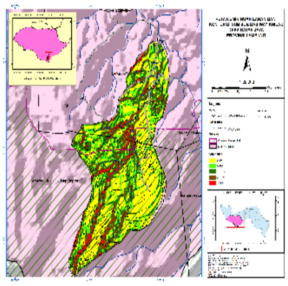


Figure 3. Slope Map

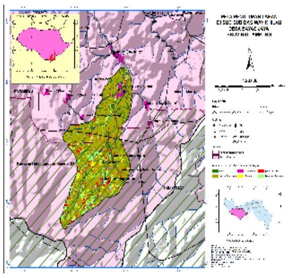


Figure 4. Land Closure Map

The results of the soil laboratory test were analyzed based on the permeability tables and the obtained land cover values (K) of primary forests, mixed gardens, shrubs, annuals, and rice fields are 0.13, 0.31, 0.23, 0.16, and 0.21 respectively. The erodibility value (K) of the soil falls into the *low to medium* category.

- Factors of Length (L) and Slope (S)

The slope of the land in the Khilau Sub-Sub-Watershed can be seen on the slope map (Figure 3.), which divides it into 5 slope classes; 0-8%, 8-15%, 15-25%, 25-45%, and >45%. The LS values and slope inclination values are 0.32 and 114.61Ha (17.29%), 0.96 and 175.85Ha (26.53%), 2.3 and 174.14Ha

(26.27%), 6.29 and 128.15Ha (19.33%), and 9.56 and 70.13Ha (10.58%) respectively.

- Land Cover Factor (CP)
  - The Crop Management Factor (C) by plant was the most dominant in the study area.
  - Soil Conservation Factor (P) is used for the influence of conservation practices in water erosion processes. In this area of study, there was no anti-erosive technique, so the value of 1 for Factor P in the entire watershed was set. Figure 4 is a map of the distribution of land use in the Khilau Sub-Sub-Watershed. The analysis was assisted by the GIS application. The CP values of the obtained 5 main land uses, i.e. forests, shrubs, annuals, rice fields, mixed gardens, are 0.001, 0.3, 0.4, 0.01, and 0.1 respectively.

- Land Designation.

From the three maps, i.e. the map of soil types, slope map, and land closure map, 14 land units were obtained.

- Calculation of Erosion Values of USLE Method (A).

When all the factor values in the USLE equation have been obtained, the erosion value calculation is viable. The result of the calculation is shown in Table 2.

b) RUSLE Method

- Rain Erosive Factors (RI).

The rain intensity was calculated with the *Mononobe* formula. The intensity of data v was measured for a concentration time of 30 minutes, which was turned into the hour unit. It was discovered that the total corrosiveness of the Khilau Sub-Sub-Watershed was 1453.94 mm/h.

- The Soil Erodibility Factor (K) is the same as that calculated through the USLE method.
- The length (L) and slope (S) factors are the same as those calculated through the USLE method.
- The Crop Management (C) and Soil Conservation (P) factors are the same as those calculated through the USLE method.
- Calculation of Erosion Values through the RUSLE Method (E_A).

It was carried out since the values of all the factors of the RUSLE Model were ready. The results of the calculation are demonstrated by Table 3.

c) MUSLE Method

- The flow coefficient/runoff coefficient factor (C) was adjusted to the standard runoff/rational coefficient.
- Regarding the tillage factor (P) on this land, there was no visible conservation or action for land improvement, so a fixed land conservation value of 1 was set.
- The obtained CP values are 0.1, 0.25, 0.3, and 0.35. The final CP value, which is 0.225, in the Khilau Sub-Sub-Watershed was obtained by figuring out the average of the total local perareal CP values in the 12m table.
- The calculation result of V_Q (the total average of the runoff volume) is 96076.17m^3. The number is attributable to the high slope of the land in the Khilau Sub-Sub-Watershed.
- The calculation result of the peak flow (Qp) is 14.7 m^3/s.
- The obtained rain corrosiveness factor is 32796.1 mm/hour.
- The Soil Erodibility Factor (K) is the same as that calculated through the USLE method.
- The length (L) and Slope (S) are the same as those calculated through the USLE method.
- The Crop Management (C) and Soil Conservation (P) factors are the same as those calculated through the USLE method.
- Calculation of the Erosion Value of the MUSLE Method (AMUSLE) in table 4.

Table 2. Calculation of Erosion Values in Khilau Sub-Sub-Watershed with USLE Method

Land Unit	Land Use	R	K	LS	CP	A (ton/ha/yr)	Space (ha)	Total Erosion (ton/year)
1	Mixed Garden	1308	0.31	2.3	0.1	93.2604	169.66	15822.9
2	Primary Forest	1308	0.13	9.56	0.001	1.625582	0.24	0.397279
3	Mixed Garden	1308	0.31	9.56	0.1	387.6389	37.01	14348.17
4	Paddy	1308	0.21	0.32	0.01	0.878976	102.31	89.92925
5	Mixed Garden	1308	0.31	0.32	0.1	12.97536	67.21	872.0454
6	Mixed Garden	1308	0.31	0.96	0.1	38.92608	164.38	6398.669
7	Annuals	1308	0.16	0.96	0.4	80.36352	10.62	853.4561
8	Annuals	1308	0.16	2.3	0.4	192.5376	0.01	2.138848
9	Shrubs	1308	0.23	0.96	0.3	86.64192	0.22	19.24963
10	Shrubs	1308	0.23	0.32	0.3	28.88064	0.55	15.88435
11	Annuals	1308	0.16	0.32	0.4	26.78784	34.16	915.0549
12	Annuals	1308	0.16	6.29	0.4	526.5485	40.59	21373.28
13	Primary Forest	1308	0.13	6.29	0.001	1.069552	30.45	32.5668
14	Mixed Garden	1308	0.31	6.29	0.1	255.0469	5.46	1254.85
Total area of land units in Khilau Sub-Sub-Watershed							662.884	
Amount of erosion in Khilau Sub-Sub-Watershed (ton/year)								61998.59
Average erosion in Khilau Sub-Sub-Watershed (ton/ha/year)								93.52852

Table 3. Calculation of Erosion Values in Khilau Sub-Sub-Watershed with RUSLE Method

Land Unit	Land Use	Re	K	LS	CP	A (ton/ha/yr)	Space (ha)	Total Erosion (ton/year)
1	Mixed Garden	1453.94	0.31	2.3	0.1	103.67	169.66	17588.35
2	Primary Forest	1453.94	0.13	9.56	0.001	1.81	0.24	0.44
3	Mixed Garden	1453.94	0.31	9.56	0.1	430.89	37.01	15949.09
4	Paddy	1453.94	0.21	0.32	0.01	0.98	102.31	99.96
5	Mixed Garden	1453.94	0.31	0.32	0.1	14.42	67.21	969.34
6	Mixed Garden	1453.94	0.31	0.96	0.1	43.27	164.38	7112.61
7	Annuals	1453.94	0.16	0.96	0.4	89.33	10.62	948.68
8	Annuals	1453.94	0.16	2.3	0.4	214.02	0.01	2.38
9	Shrubs	1453.94	0.23	0.96	0.3	96.31	0.22	21.40
10	Shrubs	1453.94	0.23	0.32	0.3	32.10	0.55	17.66
11	Annuals	1453.94	0.16	0.32	0.4	29.78	34.16	1017.15
12	Annuals	1453.94	0.16	6.29	0.4	585.30	40.59	23758.03
13	Primary Forest	1453.94	0.13	6.29	0.001	1.19	30.45	36.20
14	Mixed Garden	1453.94	0.31	6.29	0.1	283.50	5.46	1547.93
Total area of land units in Khilau Sub-Sub-Watershed							662.8843	
Amount of erosion in Khilau Sub-Sub-Watershed (ton/year)								69069.23
Average erosion in Khilau Sub-Sub-Watershed (ton/ha/year)								104.19

Table 4. Calculation of Erosion Values in Khilau Sub-Sub-Watershed with MUSLE Method

Land Unit	Land Use	R	K	LS	CP	A ton/ha/th	Broad (Ha)	Total Erosion (ton/year)
1	Mixed Garden	32796.066	0.31	2.3	0.1	2338.36	169.66	396734.49
2	Primary Forest	32796.066	0.13	9.56	0.001	40.76	0.24	9.96
3	Mixed Garden	32796.066	0.31	9.56	0.1	9719.44	37.01	359758.16
4	Paddy	32796.066	0.21	0.32	0.01	22.04	102.31	2254.84
5	Mixed Garden	32796.066	0.31	0.32	0.1	325.34	67.21	21865.18
6	Mixed Garden	32796.066	0.31	0.96	0.1	976.01	164.38	160436.68
7	Annuals	32796.066	0.16	0.96	0.4	2014.99	10.62	21399.08
8	Annuals	32796.066	0.16	2.3	0.4	4827.58	0.01	53.63
9	Shrubs	32796.066	0.23	0.96	0.3	2172.41	0.22	482.65
10	Shrubs	32796.066	0.23	0.32	0.3	724.14	0.55	398.28
11	Annuals	32796.066	0.16	0.32	0.4	671.66	34.16	22943.58
12	Annuals	32796.066	0.16	6.29	0.4	13202.38	40.59	535901.83
13	Primary Forest	32796.066	0.13	6.29	0.001	26.82	30.45	816.56
14	Mixed Garden	32796.066	0.31	6.29	0.1	6394.90	5.46	34916.18
Total area of land units in Khilau Sub-Sub-Watershed							662.88	
Amount of erosion in Khilau Sub-Sub-Watershed (ton/year)								1557971.11
Average erosion in Khilau Sub-Sub-Watershed (ton/ha/year)								2350.29

3.2 Discussion

a. USLE Method

With the USLE method, the calculation result of the annual average soil loss of the Khilau Sub-Sub-Watershed was around 61998.59 (t/year) or in a specific rate of 93.53 (t/ha/year). A large spread is seen in the distribution of the erosion per type of land use in the watershed, with a variation of erosion values, from the lowest, 0.4 t/Ha/year, to the highest, 21373.28 t/Ha/year (Table 2). It appears that the highest risk of erosion lay on hills and in areas with steep slopes (526.5485 t/year) with a slope range in the range of 25% to 45% (steep).

Judging from the slope, the areas with strong relief were the hills (slope > 20%), while the lowest erosion value was the flat-topped areas (rice fields) with a slope level of 0-8%. With the USLE Method, LS is effective for a short slope (<300 m) and is not suitable for a concentrated flow or that with a long slope as at the beginning of its development, it was intended to predict soil erosion of slopes that tend to be flat and homogenous without taking into account erosion in areas with strong relief and complex basins [19]. USLE cannot be applied if the slope length is less than 4 meters since the erosion of a slope of that length is mostly caused by erosion between grooves. As for slope erosion, it is often overlooked [20].

b. RUSLE Method

In Table 3, the average erosion potential value of the Khilau Sub-Sub-Watershed with the RUSLE Method is 69069.23 tons/year, equivalent to 104.19 tons/ha/year. The obtained highest erosion potential in land unit 12 was in the form of annuals of 585.30 tons/ha/year, equivalent to a specific rate of 23758.03 tons/year with a slope level of 25%-45% (steep).

c. MUSLE Method

Based on Table 4, the erosion values with the MUSLE model were different from the results with the USLE and RUSLE methods. The highest erosion potential in land unit 12 was in the form of annuals of 13202.38 tons/Ha/th with a slope level of 25%-45% (steep). The average annual land loss in the Khilau Sub-Sub-Watershed was about 1,557,971.11 (tons/ha/th), equivalent to a specific rate of 2,350.29 (tons/ha/th).

d. Comparison of the Three Models

All the three models could be well applied in the study area. The USLE, RUSLE, and MUSLE models' predictions of the potential erosion in the Khilau Sub-Sub-Watershed were 93.53 tons/ha/th, 104.19 tons/ha/th, and 2350.29 tons/ha/th respectively. The largest erosion values of the steep slope land (25-45%) with the methods were 526.5485 tons/Ha/th (USLE), 585.3 tons/Ha/th (RUSLE), and 13202.38 tons/Ha/th (MUSLE). The lowest erosion values of the declivous slope land (0-8%) with the methods were 0.879 tons/Ha/th (USLE), 0.94 tons/Ha/th (RUSLE), and 22.04 tons/Ha/th (MUSLE).

With the USLE and RUSLE models, the precipitation, K, LS, and CP values (the topographic factors) did not change. The erosion patterns were very similar, given the climate, nature of bedrock, morphology, and characteristics of the ground cover were the same. On the lowest slopes, the LS factor did not greatly affect the erosion value, but the soil erosion was influenced by a combination of greater K factor (soil erodibility) values and the low C (vegetation cover) factor. This agrees with the results of the study of Efthimiou *et al.* (2020) [19]. The soil loss was due to the high values of the R (potential for precipitation erosion) factor.

Locally, the ratio of the maximum erosion values through the USLE, RUSLE, and MUSLE methods with each applied on a steep slope (25-45%) was 9:10:25. From the ratio, it is obvious that the greatest erosion value was that with the MUSLE method. The ratio of the minimum erosion values through the USLE, RUSLE, and MUSLE methods with each applied on a declivous slope (0-8%) was 9:10:25. Considering the ratio, the greatest erosion value was also obtained from the MUSLE method. These results confirm the theory that great erosion occurs on steep slopes.

Covering the entire watershed area, the ratio of the USLE and RUSLE erosion potential values was 9:10. The analogy ranged from 0.86:1 to 0.9:1. It means that the area has a diverse landscape with a complex hillside profile, causing reduction in the value of the LS factor towards the USLE value in a flat zone. The effect of a high LS value visible in the highest zone (slope > 20%). Despite the fact that the values were close, there were differences in the results of these two models. Given its linear character, a single-factor change affects the analogous change of the erosion rate.

The USLE model was designed with a predominant attention to the amounts of average rainfall and maximum rainfall of the land, while the RUSLE Model relied more on the intensity of the 30-minute rain and its magnitude. The advantages of the RUSLE model are the data simplicity and computing needs. However, in its application, the suitability of the model to the area studied greatly affects the results. So, it is often necessary to calibrate the valid empirical data with its origin.

The prediction results of the MUSLE model indicate that the erosion potential values were 20 times higher than those with the USLE and RUSLE models, especially on the hills and lands having steep slope characteristics in the watershed. It explains the magnitude of the topographic influence, especially on the land slope the aggressiveness of the climate was unfavorable for. The equation of the MUSLE model focuses on the volume and coefficient of the very large runoff of a steep slope land. In the calculation of peak discharge (QP), rational equations calibrating their regional characteristics are used. On a steep land, the volume of a runoff is influenced more by the inclination of the slope which is large compared to the nature of the soil texture.

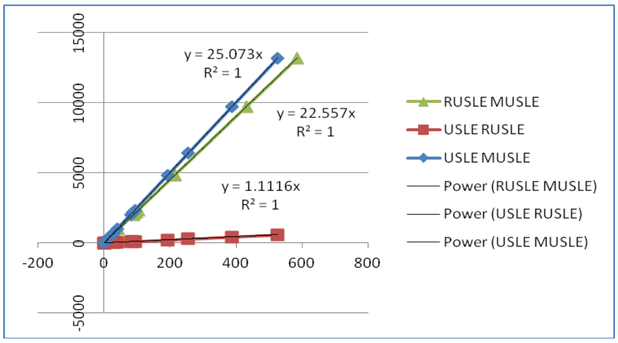


Figure 5. Comparison Chart of 3 Methods.

Among the three models, the MUSLE model resulted in the highest erosion rate, but the R factor was more effective in this model. The results of the comparison of the three models show very close average values, the determination coefficient of R2, which is 1, confirms the presence of a strong correlation among the three models.

The results with the MUSLE method in this study are comparatively in line with the nature of the data, which relied on the nature and topography of the region. Taking into account the results with this model, it is safe to regard the MUSLE model as the most suitable for the topography of steep slopes. Several researchers have enlightened people on the effect of erosion on a land with varied topographic conditions (Abdo and Salloum, 2017; Cunha *et al.*, 2017; Imamoglu and Dengiz, 2016) [21, 22, 23].

Data availability and quality greatly affect the results of potential erosion calculation. Models with the inclusion of empirical elements are the most ideal to apply, especially those with the GIS system. The optimal resolution of the GIS system along with detailed and realistic topography and land characteristics plays a vital role. It is viable for such models for erosion potential calculation as USLE, RUSLE, and MUSLE to continue developing with the GIS System.

The average amounts of erosion per year in the Khilau Way sub-sub-watershed with the USLE and RUSLE methods fell into the *medium* category (S), while with the MUSLE method, the erosion amount fell into the *very heavy* category (SB). High erosion rates were visible on the hills and lands characterized by steep slopes in the Khilau Sub-Sub-Watershed. This statement is consistent with Tung Gia Pham *et al.* (2018) [24], who state it is proven that erosion exponentially increases according to the degree of the slope's inclination. The kinetic energy of rain remains constant while the transport travels downward due to an increase in the kinetic energy of the runoff [25]. This suggests that erosion is active in the upper reaches of the Way Khilau Sub-Sub-Watershed and will result in severe soil damage due to land use, lithology, and climate aggressiveness if no preventive conservation is immediately carried out.

The generated erosion potential map might be worth discussing and could serve as one of the support tools to help the government or others to plan soil protection and conservation scenarios as the manifestation of intervention to control erosion in accordance with the level of the erosion hazard in the Way Khilau Sub-Sub-Watershed.

4.0 CONCLUSION

The USLE and RUSLE soil erosion models provide relatively similar results, but the MUSLE model shows higher spatial differences in erosion potential compared to other models. As shown in the research results of Djoukbala et al. (2018), Prado-Hernández et al. (2017), Krisnayanti et al. (2018), and Cârdei (2010) [2, 26, 27, 2 8]. The results of the MUSLE method in this study are relatively best suited to the nature of the data, which depends on the nature and topography of the region. The results of the MUSLE model in this study area make it possible to consider it as the most suitable model for steep slope topography.

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